TRANSMITTER WITH TRANSMITTER CHAIN PHASE ADJUSTMENT ON THE BASIS OF PRE-STORED PHASE INFORMATION

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

[0001] The present invention relates to a transmitter, more particularly to phase adjustment of a transmitter chain comprising a quadrature modulator, a variable gain amplifier, an up-converter, and a variable gain power amplifier.

[0002] The present invention further relates to a phase adjuster, to a method of adjusting an overall phase of a transmitter chain, and to a communication device with a phase adjuster in a transmitter chain.

[0003] Such a transmitter can be a transmitter in a full-duplex direct sequence spread-spectrum CDMA system, or any other suitable system with a high dynamic range transmitter output signal.

2. DESCRIPTION OF THE RELATED ART

[0004] Full-duplex CDMA systems are known in which transmitters have a high dynamic range output signal, typically a dynamic range of more than 70 dB. Newer CDMA systems, but also other systems, are referred to as linear modulation systems in which information is carried on amplitude as well as on phase. In such systems non-linear amplifiers cannot be adopted because the amplitude of a modulated signal varies within a wide range, i.e., the modulated peak signal envelope exhibits large fluctuations. Therefore, amplifiers in a transmitter chain need to be very linear. Particularly for a variable gain power amplifier that amplifies an up-converted signal of high frequency, e.g. in a GHZ

band, meeting linearity requirements over a wide range is not easy. Typically, such variable gain power amplifiers are optimized in efficiency at maximum signal output but have poor efficiency at low signal output.

SUMMARY OF THE INVENTION

[0005] It is an object of the invention to provide a transmitter with a phase adjuster in a transmitter chain that adjusts an overall phase of the transmitter chain thereby at least taking into account simultaneous gain changes of gains of a variable gain amplifier and a variable gain power amplifier.

[0006] It is a further object of the invention to provide such phase adjustment that largely uses a priori information of characteristics of such a transmitter chain, such as its phase and gain characteristics.

[0007] In accordance with the invention, a transmitter is provided comprising:

a quadrature modulator for providing a quadrature modulated signal from a pair of quadrature base band signals;

a variable gain amplifier for providing an amplified quadrature modulated signal;

an up-converter for up-converting said amplified quadrature modulated signal to a higher frequency signal;

a variable gain power amplifier for providing an amplified higher frequency signal from said higher frequency signal, said amplified higher frequency signal comprising amplitude and phase information; and

phase adjusting means for adjusting an overall phase of a transmitter chain including said quadrature modulator, said variable gain amplifier, said up-converter, and said variable gain power amplifier, said overall phase being adjusted on the basis of pre-stored phase information reflecting phase changes

due to simultaneous gain changes of gains of at least said variable gain amplifier and said variable gain power amplifier.

[0008] The invention is based on the recognition of the need to make a phase adjustment in the transmitter chain when improving the overall transmitter efficiency by decreasing the gain of the variable gain power amplifier that operates at an radio frequency, and thereby simultaneously increasing the gain of the variable gain amplifier that operates at an intermediate frequency. The invention is further based on the recognition to make such a phase adjustment even when the total gain of the transmitter chain remains constant from one gain state to another gain state. The invention is further based on the recognition that usually no full phase compensation is need because transmitters work according to standards that allow predetermined maximum phase variations over the dynamic range of the signal and with frequency. In this respect, phase variations should not be too large because, when transmitting from a portable communication device to base station of a system, such phase variations could lead to a poor bit error rate at the base stations, and, eventually, a call drop. Based on these recognitions, the inventor had considered that overall phase adjustment on the basis of pre-stored information was feasible where others may have thought such an overall phase adjustment might be impractical or even impossible to practically implement.

[0009] In an embodiment the pre-stored information is stored in a look-up table, and, upon a gain state change of the variable gain power amplifier, from corresponding entries in the look-up table information is used to determine the gain of the variable gain amplifier, and the phase adjustment value.

[00010] In an embodiment, the overall phase of the transmitter chain is adjusted by phase rotating quadrature base band signals prior to modulation. At constant gain of the transmitter chain,

such a phase adjustment effectively rotates the so-called IQ-constellation. Rotation of the IQ-constellation as such is known in the art, for instance from the US Patent No. 5,892,774 the contents of which is herewith incorporated by reference. More particularly, in US 5,982,774 phase rotation is shown in Fig. 3 thereof and described in column 6, lines 30-40 where it is disclosed that a phase encoder rotates an (X_I, X_Q) pair by an angle $\Phi_n[k]$ to produce a signal (Y_I, Y_Q) at its output.

[00011] In various embodiments, the transmitter may include a temperature sensor, a battery voltage sensor, and a signal level sensor for providing a DC-signal indicating the amplitude of the output signal at the variable gain power amplifier. In such embodiments, the look-up table may be made multi-dimensional so as to reflect characteristics of the transmitter chain at different temperatures, different battery voltages, and different amplitudes of the RF output signal. In still another dimension, the look-up table may reflect characteristics of the transmitter chain at different frequencies.

[00012] In an embodiment, the look-up table may also contain phase characteristic data for an RF filter comprised in the transmitter chain, or for other components comprised in the transmitter chain.

BRIEF DESCRIPTION OF THE DRAWING

[00013] Figure 1 shows an embodiment of a transmitter according to the invention, in communication with a base station.

[00014] Figure 2 shows another embodiment of a transmitter according to the invention.

[00015] Figure 3 shows rotation of an IQ-constellation at constant signal amplitude.

[00016] Figure 4 shows a look-up table according to the invention.

[00017] Figure 5 shows a flow-chart illustrating calculation of a phase adjustment value according to the invention.

[00018] Throughout the figures the same reference numerals are used for the same features.

DESCRIPTION OF THE DETAILED EMBODIMENTS

[00019] Figure 1 shows an embodiment of transmitter 1 according to the invention, in communication with a base station 2. Transmitter 1 comprises a quadrature modulator 3 comprised of multipliers 4 and 5, an adder 6, a quadrature phase shifter 7 and an oscillator 8. Quadrature modulator 3 modulates a pair of quadrature base band signals Tx_I and Tx_Q. Transmitter 1 further comprises a variable gain amplifier 9 for amplifying an intermediate frequency output signal from quadrature modulator 3, and an up-converter 10 comprised of mixers 11 and 12, an adder 13, a phase shifter 14 and an oscillator 15. Up-converter 10 provides a radio frequency signal to an RF filter 16. Transmitter 1 further comprises a variable gain amplifier 17 that is coupled to an antenna 18 via a duplexer 19. Duplexer 19 is configured such that a communication device comprising transmitter 1 and further a receiver Rx (not shown in detail here) operates in a full-duplex mode. Transmitter 1 further comprises a base band unit 20 comprising a processor and storage unit 21, digital-to-analog converters 23 and a memory 24 comprising a look-up table (LUT) according to the invention. Base band unit 20 provides control signals C1, C2 and C3 to at least control the gain of variable gain amplifier 9 and variable gain power amplifier 17. In an embodiment, transmitter 1 comprises an RF signal level detector 25 that produces a DC output signal indicative of the amplitude of the transmitted RF signal, a temperature sensor 26, and a battery voltage sensor 27. From information comprised in look-up table 24, processor unit 21 calculates the required phase

change and controls a quadrature phase rotator 28 such that the IQ-constellation is rotated. In the embodiment given, modulator 3 is implemented in hardware.

[00020] Figure 2 shows another embodiment of transmitter 1 according to the invention. In this embodiment, modulator 3 is implemented in software and processor unit is programmed accordingly. Such programming is straightforward once the functionality of the modulator is specified. The programmed modulator has the same functionality as modulator 3. Also phase rotation prior to modulation is implemented in software here.

[00021] Figure 3 shows rotation of an IQ-constellation at constant signal amplitude. In a first state, the transmitted RF signal at the output of variable gain power amplifier 17 has amplitude Aand has instantaneous in-phase and quadrature components I(t) and Q(t), t being time. In a second state, the transmitted RF signal has amplitude A'=A but with a different phase. In the first and second states the overall gain of the transmitter chain is constant, but the gains of variable gain amplifier 9 and variable gain power amplifier 17 are different. The first state represents high output power at the output of variable gain power amplifier 17, and the second state represents low output power at the output of variable gain power amplifier 17. According to the invention, phase variation $\Delta\Phi$ caused by gain changes is compensated through rotation of the IQ-constellation over $\Delta\Phi$ in the opposite direction, so that, ideally, the second state becomes the same as the first state. Because in the second state variable gain power amplifier 17 operates at reduced power, overall transmitter efficiency has improved. Because standards allow predetermined phase variations, compensation does not have to be full compensation. Effects of aging or the like may be analyzed at a design stage of transmitter 1, e.g. through simulation. From such simulations it can be established that over

the lifetime of transmitter 1 phase variations through aging will remain within the specifications as of such standards.

[00022] Figure 4 shows look-up table 24 according to the invention. Look-up table 24 contains entries at gain states variable gain power amplifier 17, for variable gain power amplifier 17, for variable gain amplifier 9, and for RF band pass filter 16. Shown are respective gains $G1_{PA}$, $G1_{VGA}$, and $G1_{BPF}$, and respective phases $\Phi1_{PA}$, $\Phi1_{VGA}$, and $\Phi1_{BPF}$ at STATE 1 for variable gain power amplifier 17, for variable gain amplifier 9, and for RF band pass filter 16. Similarly, at STATE 2 respective gains $G2_{PA}$, $G2_{VGA}$, and $G2_{BPF}$, and phases $\Phi2_{PA}$, $\Phi2_{VGA}$, and $\Phi2_{BPF}$ are shown, and at STATE n respective gains Gn_{PA}, Gn_{VGA}, and Gn_{BPF}, and phases Φn_{PA}, Φn_{VGA}, and Φn_{BPF}. With transmitter state change from state 1 to state 2, the gain of variable gain power amplifier 9 becomes $(G1_{VGA} \times G1_{PA}) / G2_{PA}$ so that the overall transmitter gain remains constant, and $\Delta\Phi$ becomes $\Sigma\Phi2_i - \Sigma\Phi1_i$, Σ being a summing operator and i being a running variable of all phases in a particular entry of look-up table 24. Further indicated in look-up table are 'TEMP', 'BATTERY VOLTAGE', and 'FREQUENCY', indication that look-up table may be multi-dimensional in temperature, battery voltage, and frequency.

[00023] The data may be put in look-up table 24 at a manufacturing stage, and may be acquired from simulations, from measurements with a vector analyzer, from information from design engineers, or the like. Because no full phase compensation is needed in practice, such data may be acquired for an exemplary transmitter without the need to perform measurements for each and every transmitter, at least no extensive measurements going far beyond usual testing of ICs. Even with process spread, specifications may then be well within requirements set by standards.

[00024] Figure 5 shows a flow-chart illustrating calculation of

phase adjustment value $\Delta\Phi$ according to the invention. In block 30, calculation starts, In block 31, processor 21 calculates $\Delta\Phi$ thereby using input variables 'RF-LEVEL', 'TEMPERATURE', 'BATTERY VOLTAGE', and 'FREQUENCY'. In block 32, processor 21 outputs the calculated $\Delta\Phi$, and in block 33 phase compensation stops.

[00025] In view of the foregoing it will be evident to a person skilled in the art that various modifications may be made within the spirit and the scope of the invention as hereinafter defined by the appended claims and that the invention is thus not limited to the examples provided. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim.